AR-009-250

DSTO-TR-0171

Detection of Small Targets in Sea Clutter Limited Environments Using Phase Information

B. Reid

19960212 237

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

Detection of Small Targets in Sea Clutter Limited Environments Using Phase Information

Brian L. Reid

Microwave Radar Division
Electronics and Surveillance Research Laboratory

DSTO-TR-0171

ABSTRACT

Current techniques used to discriminate between sea clutter and targets, based on using the amplitude of the reflected signal, are described and applied to data collected experimentally. A new method which uses the information contained in the phase of the reflected energy is described and is also applied to this data set and a significant improvement in the ability to detect a small target within this data is demonstrated. Issues associated with the implementation of this new algorithm in an existing radar system are then considered and several feasible approaches are described.

RELEASE LIMITATION

Approved for public release.

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

Published by

DSTO Electronics and Surveillance Research Laboratory
PO Box 1500
Salisbury, South Australia 5108 Australia

Telephone: (08) 259 5555
Fax: (08) 259 5200

AR-009-250
September 1995

Detection of Small Targets in Sea Clutter Limited Environments Using Phase Information

EXECUTIVE SUMMARY

Existing maritime surveillance radars discriminate between natural features and potential targets based on the amplitude of the reflected energy in each of the resolution cells. Although most new maritime surveillance radars use coherent waveforms, the phase information is largely ignored. In situations in which there is a substantial amount of reflection from the sea surface (high sea states, steeper lookdown angles, etc), then the use of amplitude alone as a discriminant will result in an unacceptably high false alarm rate when attempting to detect small targets.

This report describes the current approach to detection, based on amplitude alone, and then proposes a new method of discriminating between clutter and targets which uses the phase information available from modern coherent radars. This approach is applied to data collected experimentally using a cliff top radar staring over the ocean and the performance of the new phase based discriminant is evaluated for this data set. Comparison is made with conventional approaches to detection using the same data set to demonstrate the advantages of utilising phase information. This method is then further developed to enable a practical implementation of the new discriminant using existing radar architectures and signal processing capabilities.

Author

Brian L. Reid
Microwave Radar Division

Brian Reid graduated from the University of Adelaide in 1983 with an degree in Electrical and Electronic engineering. Apart from a 16 month period in which he worked as a Research Assistant at the University of Adelaide, he has been employed as an engineer in the Microwave Radar Division of DSTO. In this capacity he has been involved with Non Cooperative Target Recognition and Synthetic Aperture Radar systems and was the Project Leader for the AuSAR Synthetic Aperture Radar project. During the period March 1993 to May 1994 he was attached to the Defence Research Establishment in Ottawa, Canada, where he was involved in research into target detection techniques for maritime radars.

Contents

Figures

1. Introduction

The radar backscatter from the surface of the sea and it's effect on the performance of maritime surveillance radars has been studied for many years.[1,2,6]. Most of this work has been concentrated on the study of the statistics of the spatial and temporal properties of the amplitude of the returned signal while the coherent properties of the clutter have been largely ignored. This report describes a study done by the author during an attachment to the Defence Research Establishment in Ottawa from the Defence Science and Technology Organisation in Australia. The study was aimed at investigating techniques which could lead to an improvement in the probability of detecting small maritime targets (and/or decreasing the probability of false alarms) when using maritime surveillance radars by using the information contained in the phase of the returns from a coherent and motion compensated airborne radar. The study was prompted for several reasons including:

- the APS-506 radar used as the primary wide area sensor on the Canadian Aurora maritime patrol aircraft is currently undergoing an upgrade program including the addition of a high resolution Synthetic Aperture Radar (SAR) mode [4,5]. This mode necessitates the inclusion in the radar system of a powerful signal processing capability which could be made available to the target search modes of the radar as well as the imaging modes,

- the requirement for motion compensation of the radar returns for the SAR mode of this radar results in motion compensated data being available to the target search modes which previously has not been the case, and

- a further upgrade to this radar will replace the non maintainable analogue scan converter with a more powerful and flexible digital scan converter in which more sophisticated detection algorithms, aimed at improving the detection performance of the system, could be implemented.

The broad goal of the study was to answer the question - "How can the available processing power and the availability of motion compensated data be exploited in order to improve the wide area target detection capabilities of this (or similar) radars in a clutter limited environment?"

2. Current Techniques for the Detection of Targets in Sea Clutter.

Most maritime surveillance radars in operation today approach the problem of discriminating between targets and sea clutter by searching for "unnaturally bright" returns. A threshold is set, above which, a return is detected to be a target. By using an estimate of the Probability Density Function (PDF) for the amplitude of the sea clutter, the threshold can be determined which results in an acceptable Probability of False Alarm (PFA) in the presence of clutter alone. There are several techniques that are currently used to derive an estimate of the PDF of the amplitude of the sea clutter including, more recently [3], the use of the "K distribution".

2.1. Amplitude characteristics of sea clutter

There are many natural factors that determine the characteristics of the radar backscatter from the surface of the sea including the sea state, the wind speed and direction and the direction of the sea. There are also several radar parameters that will effect the measured backscatter including the radar carrier frequency, the bandwidth (or range resolution), antenna beamwidth, receive and transmit polarisations, and the antenna angle of incidence relative to the sea surface. Early designs of radars for maritime surveillance sought to decrease the amplitude of the return from sea clutter relative to the return from a solid target by increasing the resolution of the radar so that the area of sea surface contributing to the return in any one range cell is smaller. However, the amplitude characteristics of the sea clutter in these circumstances appear to be "spiky" in nature and the performance gains were not as great as expected for the reduction in clutter cell size. An example of experimentally derived clutter is shown in Figure 1 and the time history for a particular range cell of this clutter is shown in Figure 2. The spiky appearance of sea clutter as seen in this figure is described by a "long tailed" histogram (for amplitude) as

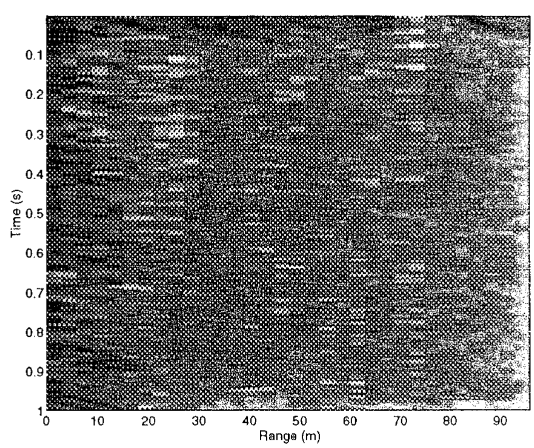

Figure 1 Raw sea clutter data (amplitude plot) collected using the AuSAR radar in a ground based configuration.

shown in Figure 3. This data was collected by the AuSAR radar operated by DSTO in a ground based configuration [7].

It is the sea clutter spikes which contribute to the False Alarm Rate and present us with a problem when attempting to set a threshold that is low enough to detect small targets yet high enough to reject sea clutter.

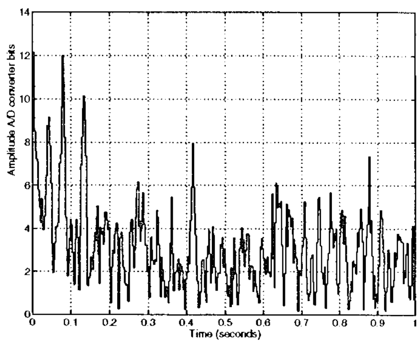

Figure 2 ***Amplitudes across a typical range bin for the data shown in figure 1.***

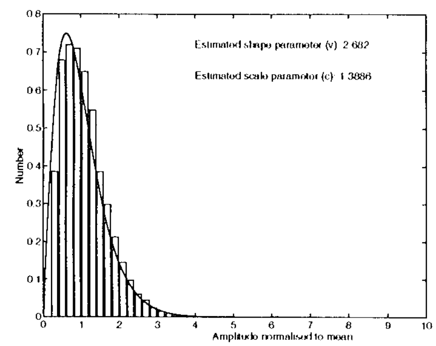

Figure 3 ***Distribution of amplitudes for the pixels in the AuSAR ground based data***

2.2. Setting of a threshold using the K distribution

Although the backscatter of radar energy from the sea surface is not well understood it is currently accepted [1,2,3] that the K distribution provides an acceptable model for the amplitude statistics of the backscatter under the widest range of conditions. The probability density function *p(x)* for this distribution is:

$$p(x) = \frac{2c}{\Gamma(\nu)}\left(\frac{cx}{2}\right)^{\nu} K_{\nu-1}(cx) \tag{1}$$

where ν is the shape parameter, c is the scale parameter, $K_{\nu-1}$ is the modified Bessel function of the second kind of order ν-1 and $\Gamma(\nu)$ is the Gamma function. In practice the value for the shape parameter varies between the values of $\nu = 0.1$, corresponding to very spiky data and $\nu = 20$, corresponding to approximately Gaussian distributed data

In [1] Watts shows that there is some physical justification in the use of this model based on a model of the sea surface consisting of surface ripples on top of a longer wavelength swell. The required threshold for a given probability of false alarm can be determined by first finding the scale and shape parameters of a K distribution which best fits a sample of the measured sea clutter return. These parameters can then be

used in the expression below to find a threshold for a selected probability of false alarm for single pulse detection given by:

$$P(x > X_T) = \frac{2c^{\nu}}{\Gamma(\nu)} X_T^{\nu} K_{\nu}(2cX_T) \tag{2}$$

where X_T is a threshold value and $P(x > X_T)$ is the probability that a random sample x of the distribution described in equation (1) is greater than this threshold.

For a given PFA this expression can be solved numerically to give us the corresponding value of threshold. In practice, the PFA is closely related to the operator workload and probability of detection during a mission - a high PFA will lead to an unacceptably high workload while a low PFA requires a threshold that would be too great to allow small targets to be detected. A practical radar would allow the operator to set a value for the PFA, consistent with an acceptable workload. As environmental conditions changed and radar parameters were altered the radar would automatically vary the threshold to maintain a constant false alarm rate (CFAR). A typical plot of PFA vs normalised threshold (normalised to the mean of the amplitude) for a particular setting of the shape and scale parameters is given in Figure 4.

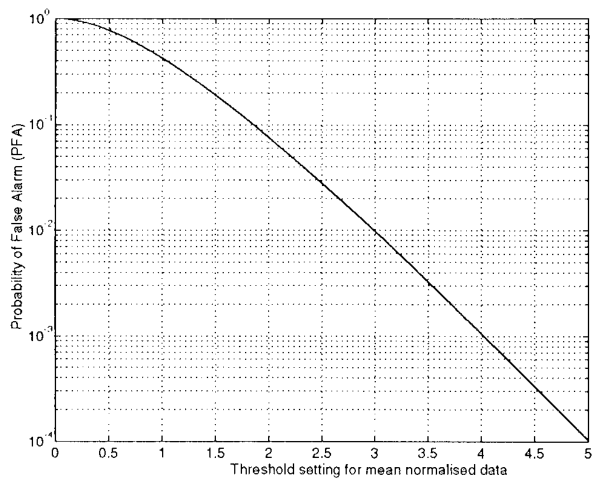

Figure 4 Typical PFA versus threshold plot as calculated for the data in figure 1.

2.3. Estimating the K parameters.

Estimating the parameters of the K distribution from a set of sample data to set the threshold level has been found to be a non trivial problem. The form of the expression

for the K distribution is difficult to work with and must be solved numerically. This restricts the use of a two dimensional search through parameter space to find the parameters that provide the distribution closest to a particular test sample. Several techniques have been used to approach this problem [1,2,3]. Two common techniques are described below.

2.3.1. Method of moments

It is possible to find relatively simple expressions for the shape and scale parameters of the K distribution as functions of the second and fourth moments for this distribution. These moments can easily be estimated from the histogram of a given sample of a random variable x from the expressions below [9]:

$$m_2 = E\{x^2\} = \sum_{k=1}^{N} k^2 h_k \tag{3}$$

$$m_4 = E\{x^4\} = \sum_{k=1}^{N} k^4 h_k \tag{4}$$

where N is the number of histogram bins, and h_k is the amplitude of the kth bin. In our case, the random variable x is the amplitude of the radar return within a particular range cell for a single pulse. Once these moments are known then the following expressions can be used to calculate the values of the scale and shape parameters for the K distribution with identical second and fourth moments as the sample [1]- ie. the scale and shape parameters for the K distribution that most closely matches the distribution of our test sample.

$$\nu = \left(\frac{m_4}{2m_2^2} - 1 \right)^{-1} \tag{5}$$

$$c = \sqrt{\frac{\nu}{m_2}} \tag{6}$$

Raghavan [3] found that this technique did not perform well when the size of the test sample was small and/or the level of quantisation noise in the test sample was large. Generally in these cases the estimate from this method gave conservative results - ie. gave K distribution parameters in which the resulting threshold was set too high. This method is particularly susceptible to test data sets in which a target is unwittingly present.

2.3.2. Arithmetic and geometric mean based

A method proposed by Raghavan [3] was found to be less susceptible to these problems within the test sample. In this method the similarity between the K distribution and the simpler Gamma distribution given below is exploited. The probability density function for the Gamma distribution is given by:

$$G(x) = \frac{x^{\beta-1}}{b^{\beta}\Gamma(\beta)} e^{-\frac{x}{b}} \tag{7}$$

where β is the Gamma shape parameter and b is the Gamma scale parameter. It is straight forward to derive a relationship between the arithmetic and geometric means of the sample distribution and the scale and shape parameters of the corresponding Maximum Likelihood (ML) Gamma distribution. Specifically, if the arithmetic and geometric means of the distribution, m_a and m_g, are derived from the following equations:

$$m_a = \frac{1}{N}\left(x_1 + x_2 + x_3 + \ldots + x_N\right) \tag{8}$$

$$m_g = \sqrt[N]{x_1 x_2 x_3 \ldots x_N} \tag{9}$$

then the ML Gamma shape and scale parameters, β and b, for the sample are related by the following equations:

$$\frac{m_a}{m_g} = \beta e^{-\psi(\beta)} \tag{10}$$

$$b = \frac{m_a}{\beta} \tag{11}$$

where $\psi(\beta)$ is the Digamma function. We can compute these two means using our test sample and then use the above expressions to find the parameters for the Gamma distribution with the same geometric and arithmetic means as our test data. (ie. the ML estimate of these parameters). By numerically solving equations (12) and (13) below:

$$\beta = \left(\frac{4\nu\Gamma^2(\nu)}{\pi\Gamma^2(\nu + 0.5)} - 1\right)^{-1} \tag{12}$$

$$c = \frac{2}{\sqrt{\pi}} \frac{\Gamma(\nu + 0.5)\Gamma(1.5)}{m_a \Gamma(\nu)} \tag{13}$$

we can take the Gamma parameters derived as above and calculate the parameters for the K distribution with identical first and second moments. That is, we can derive the parameters (ν and c) of the K distribution that has (approximately) the same arithmetic and geometric means as our test set. This method is a numerically fast method of estimating the Maximum Likelihood K parameters at the cost of greater complexity when compared to the method of moments approach described by Watts.

2.4. Techniques currently used to improve the signal to clutter ratio.

The same techniques used to improve the signal to noise ratio in thermal noise limited environments are not applicable to improving the signal to clutter ratio in clutter limited environments. For example, an increase in transmitter power will increase the amplitude of both the clutter and the return from any targets. In addition to this, the longer time constants of sea spikes will result in little (if any) improvement after pulse to pulse non-coherent (or amplitude only) integration.

Scan to Scan integration is a commonly used technique that is successful in most instances at improving the signal to clutter ratio before the application of a threshold. With this technique several samples of the same range line taken at time intervals greater than the average time constant of a sea spike (typically greater than 100 msec or so) are added non coherently. In practice this time interval corresponds to the interval between visits to the same position by a rotating (or "scanning") antenna. In older style radars, scan to scan integration is achieved with the use of a long persistence screen while in newer maritime surveillance radars, such as the APS-506, this technique is implemented with digital electronics as a function of the Digital Scan Converter.

Although this is a proven method of improving the signal to clutter ratio in clutter limited environments it has some problems including the length of time over which the target must be observed, and the combined motion of the target and aircraft during this interval. The next section describes some work aimed at improving the signal to clutter ratio using information gained over a much shorter pulse to pulse time period (typically 1 to 10 msec) rather than scan to scan (typically 1-10 seconds).

3. Pulse To Pulse Coherent Processing

There are several methods currently used to discriminate between "targets" and "clutter" which take advantage of information contained in the radar return from

(several) consecutive pulses from a coherent radar. The most common of these is Moving Target Indication (MTI) processing in which the different velocities associated with the clutter and a target result in different Doppler offsets when their returns are analysed in the frequency domain. This technique works reasonably well for discriminating between ground targets with a constant velocity and ground clutter because of the fact that most of the ground clutter is relatively stationary, which results in a relatively narrow Doppler spectrum. There are problems when using this technique over water however due to the much wider and non stationary spectrum observed when analysing the radar returns from the surface of the sea. The following sections describe other approaches which are more applicable to the detection of targets in sea clutter.

3.1. Frequency-Time analysis

There are several techniques that allow the estimation of "instantaneous frequency" over time for a given time series. One such technique is the short term FFT in which the time series (which in our case corresponds to the returns from a single range cell over many consecutive pulses) is split into many short and overlapping time "segments", and the discrete Fourier Transform is applied to each of these segments. The results of the discrete Fourier Transforms can be displayed as a two dimensional array showing an estimate of the instantaneous spectrum over time. Two such arrays for a range cell containing a target plus sea clutter only and one containing only sea clutter are shown in Figures 5 and 6 respectively. The effect of a target being present within the range cell can be seen as a narrow bright line within the wider band of sea clutter. A target detection algorithm could be devised in which the frequency-time representation of the returns for each range cell could be individually tested for the presence of a narrow, bright line.

For a target with a constant velocity there will be a signal processing gain associated

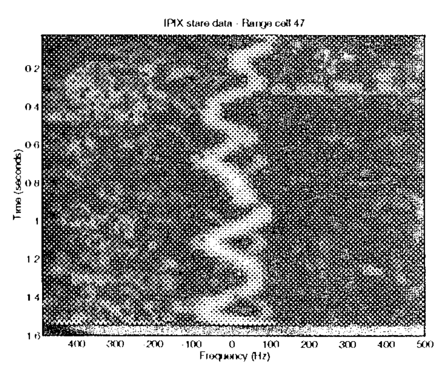

Figure 5 Frequency time analysis for range cell containing a target

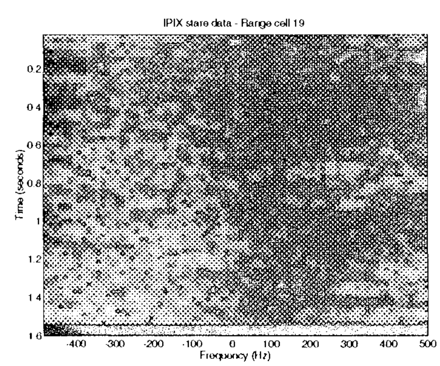

Figure 6 Frequency time analysis for range cell containing clutter only.

with the estimation of the Doppler spectrum of the radar return. For a range cell containing such a constant velocity target, the returns from each of the pulses within the short time series segment can be thought of as contributing to the amplitude of a single Doppler frequency bin. Conversely, the returns from a range cell containing a distributed target (such as sea clutter) do not exhibit the same characteristics in the frequency domain as a point target, especially so as the observation time is decreased. In this case the energy within the return is spread out over a larger portion of the spectrum with lower peak values. Thus an algorithm based on comparing the peak values within the spectrum can be used to discriminate between target cells and clutter cells.

3.2. Testing for "predicability of phase"

Another technique that is currently being investigated uses the information contained in the phase of the radar returns in a more general way than the frequency-time analysis. There are different mechanisms that generate the phase response of a target and the phase response of a patch of sea surface. In general, a small target can be modelled as a single point scatterer in which the phase measured by a radar is directly related to the distance between the radar and the target. The return from the surface of the sea however is much more complicated and not very well understood. It is generally accepted that the return from the sea is a result of the interacting returns of a very large number of individual reflectors distributed over the area of the surface within the range cell being considered. A result of the larger number of assumed scatterers is that the phase response from a range cell containing clutter is much more random compared to that of a target, which is physically constrained in how far it can move and accelerate in a given period. The combined return from a large number of everchanging reflectors on a patch of sea surface is subject to more complex constraints on motion and this is reflected in the observation of a more random phase history for range cells containing only sea clutter.

3.2.1. Plot of phase vs time for target and non-target.

The above discussion is illustrated in Figures 7 and 8 which correspond to the unwrapped phase histories for a range cell containing a target and one containing sea clutter only. These plots were generated using data collected using the IPIX experimental radar [8] looking at point targets in the ocean from a "cliff top" position. If attention is paid to the scales on these two plots then a difference between the two plots is apparent. Although the phase history for the sea clutter shows a general linear trend corresponding to an overall negative doppler, the fine detail in the two plots reveals that the target phase history shows a smoother and more "predictable" (pulse to pulse) path than the phase history from the sea clutter. A new technique that is

described below aims to exploit this difference as a tool to discriminate between target and clutter.

3.2.2. Fitting a polynomial model to the motion of the target.

The motion of the point scatterer over time can be described by the polynomial:

$$p(t) = a_0 + a_1 t + a_2 t^2 + \ldots\ldots \tag{14}$$

and the corresonding phase history as:

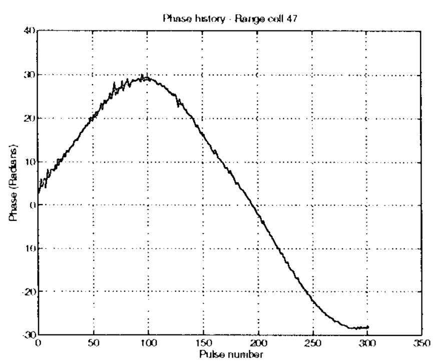

Figure 7 ***Unwrapped phase history for the return from a point target in sea clutter***

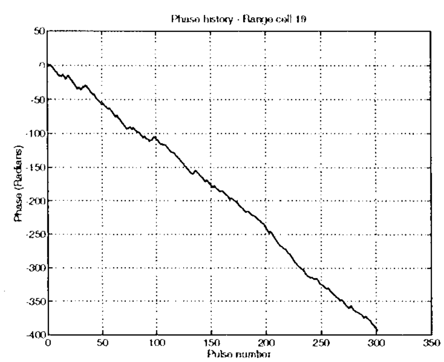

Figure 8 ***Unwrapped phase history of a range cell containing a return from the sea surface only***

$$\phi(t) = \varphi_0 + 4\pi \frac{p(t)}{\lambda} \tag{15}$$

where the coefficients $a_0, a_1, a_2 \ldots.$ are related to the initial position, velocity, acceleration, etc of the point target.

If the amplitude of the return from such a scatterer is significantly greater than the amplitude of the return from the surface of the sea in that cell (ie the Signal to Clutter Ratio or SCR is high) then the measured phase will also take the form of a polynomial as shown in equation 15. As the SCR within the cell containing the target approaches unity then then the form of the phase history for this cell will become more random and less polynomial like. It can be shown that the phase response from a point scatterer will dominate the total phase response from the scatterer plus clutter for a

Signal to Clutter Ratio greater than 3 dB. (For a SCR = 3 dB the effect of the clutter will distort the phase from the point scatterer by less than 10% of a full cycle or $\pm 30^0$.)

For a target on the surface of the ocean, the motion of the target over a short time period, corresponding to a scanning radar dwell period, (eg. 40 msec) can be approximated (to within a small fraction of the 3 cm wavelength of a typical maritime surveillance radar) by a quadratic. This is equivalent to assuming a constant acceleration of the target over this short period. We can discriminate between the return from a target and that from sea clutter by observing the phase history over such a short time period (eg. 40 pulses at 1 KHz PRF), finding the expression for the least squares fit quadratic to this measured phase history and then using the "goodness of fit" to this quadratic as a measure of how "target like" the phase history is. The mean squared error can be used as a measure of how well the quadratic fits the sampled phase history. If there is a large error associated with the best fit quadratic then either our assumption regarding the constant acceleration of the target over this short period is wrong, or the return is being generated by some mechanism other than the motion of a point target. (ie. is the return from the sea surface).

An example of the application of this algorithm to experimental data collected with the IPIX radar [8] is given in Figures 9 and 10. Figure 10 shows both the phase history for a short segment of the longer term phase history in Figure 7 and the best fit quadratic to this history. Similarly, Figure 9 shows the phase history and best fit quadratic for a segment of the phase history from a range cell containing clutter only. Clearly the quadratic fit to the phase history of the target results in a lower mean squared error than the fit for the sea clutter (as expected).

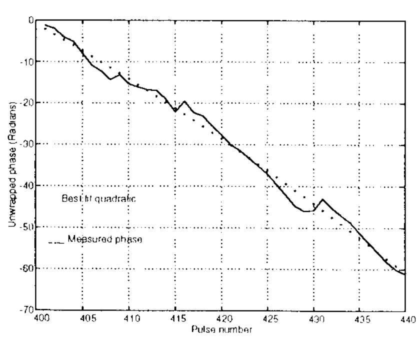

Figure 9 *Phase history from a range cell containing clutter only along with the best fit quadratic to this history*

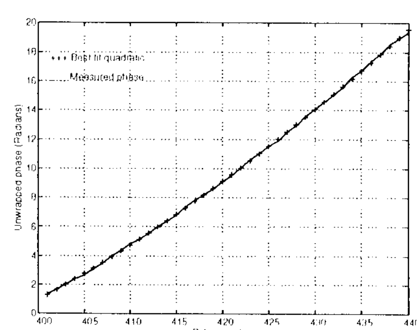

Figure 10 *Phase history returned from a cell containing a target and clutter along with the best fit quadratic to this history*

Figure 11 shows the amplitude (greyscale) plotted against range and time for raw radar data over several range bins, one of which is known to contain a target. From this image it is obvious that amplitude alone is not a sufficient discriminant between target and clutter and the application of a classical threshold to this data would result in either a missed detection or an unacceptably high False Alarm Rate. Figure 12 shows the result of "polynomial fit" processing applied to the same data set with the inverse mean squared error plotted as a greylevel on the same axes. It can be seen that in this particular data set there is a significant improvement in the signal to clutter ratio. This image was generated using 80 point (or pulse) segments of the phase history. There are trade-offs to be made in using this algorithm when choosing the order of the model being used (ie. linear, quadratic, cubic, etc), the number of pulses to be fitted to this model and the processing power required for real time implementation.

3.3. Analysis of target to clutter discriminant performance.

The performance of the technique described above can be compared to the performance of a discriminant based on amplitude alone by comparing the histograms of the amplitude distribution and the distribution for the mean squared error in the polynomial fit from range cells containing clutter and range cells containing a target plus clutter.

Figure 13 shows the comparison of amplitude histograms for clutter only cells and for a target plus clutter cell. Although the target cell shows a higher mean value it is obvious from this figure that a threshold setting which would allow the single pulse detection of the target even half of the time would result in a large false alarm rate. The effect of scan to scan integration is to narrow each of these distributions about their mean values. This would improve the false alarm rate for a given probability of

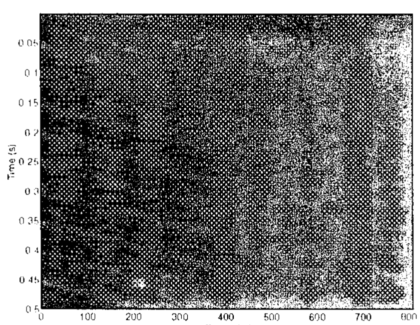

Figure 11 Amplitude plot for several range cells, one of which contains a target of small radar cross section.

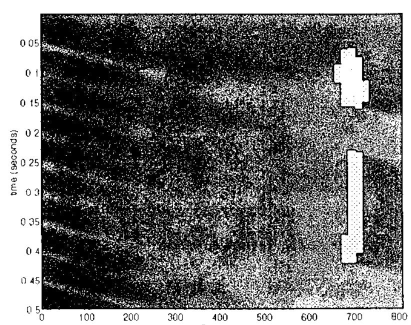

Figure 12 Plot of the inverse of the mean square error for the data whose amplitude is shown in figure 11.

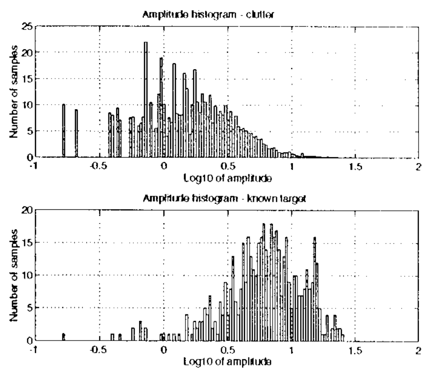

Figure 13 Comparison of amplitude histograms for a range cell containing clutter and a range cell containing a target plus clutter

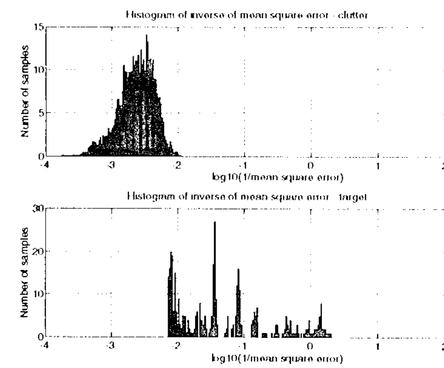

Figure 14 Comparison of histograms for quadratic fit for a range cell containing clutter and a range cell containing a target plus clutter

detection as expected (ie. decreases the area of overlap between the target distribution and the clutter distribution), but at the cost of having to observe the target for several scans.

Figure 14 shows a similar comparison of histograms for the mean square error from the polynomial fit processing for the same data set. From this comparison it can be seen that, for a given probability of detection, the false alarm rate is much smaller than would have been achieved using amplitude alone. These histograms were generated using experimental data from the IPIX radar. Non coherent scan to scan integration could still be used to improve the discrimination between target and clutter on the output of the polynomial fit algorithm.

4. Practical Considerations: A Possible Implementation In The Upgraded APS-506

The initial study that has been described in this report suggests that there are significant gains to be had in implementing a discrimination algorithm based on time domain processing of the phase. There are, however, problems associated with implementing such an algorithm in real time. In particular, the processing power and data rates of the signal processor are significant. The following discussion considers, as an example, the possible implementation of this algorithm on an existing radar - the APS-506 [5]. This radar is the Canadian variant of the APS-116 radar and is currently undergoing a significant upgrade including the addition of a high resolution imaging

mode and the replacement of the analogue scan converter with a more powerful, flexible and reliable digital scan converter.

At the maximum bandwidth of the APS-506 operating out to a range of 100 km, there are 330,000 samples collected every pulse. At a nominal PRF of 500 Hz this corresponds to an average data rate of 165 million complex samples per second or 330 Mbytes/sec. This is out of the range of conventional "state of the art" signal processors just in terms of data I/O rates alone. Clearly, if the advantages of coherent processing are to be exploited as an aid to detecting targets in clutter limited environments then a scheme must be devised which would provide the optimum trade-offs in surveillance area and hardware limitations. This section suggests some possible approaches.

4.1. Pulse to pulse processing as a post detection process.

In this implementation the Digital Scan Converter would report the position of targets, detected using the existing detection scheme, to the data collection and processing subsystem used by the Synthetic Aperture Radar modes. This subsystem would then collect data for each of the areas in which a detection was made and individually test these segments for a "target like" phase history.

One approach is to use the algorithm as a "post-process" applied to the currently implemented detection scheme based on amplitude alone. To discriminate targets from clutter, an amplitude threshold is set and a detection is declared each time the return exceeds this threshold. As this threshold is decreased the probability of detecting a small target rises along with the number of false alarms. To reduce the coherent processing load, the threshold could be lowered and only those signals that exceed the threshold would be coherently processed. Thus an overall false alarm probability could be maintained while realising an enhanced detection performance because of the lower threshold.

4.2. Pulse to pulse processing over a subset of the surveillance area.

As with other modes of the radar (eg. spotlight mode) the operator could designate a subset of the entire surveillance area that is to be processed using a coherent technique. For example, if we were to sample 4096 range bins each pulse then the I/O rate would reduce to around 8 Mbytes/sec and would provide a range extent of approximately 1350 metres distributed in an annulus centred at the position of the aircraft. If the aircraft was moving at a nominal rate of 100 metres per second then a required area could be "scanned" as the aircraft flew (ie. the 10 second revisit time of the scanning antenna is quick enough that the processed areas would overlap). A further option here would be to sample 20,000 points per pulse, giving a peak data rate of 40 Mbytes/sec and range extent of 6.7 km, and process a 72 degree sector of the antenna sweep angle.

4.3. Processing the peak detected data.

The APS-506 currently overcomes the huge data rates associated with the high sample rates by preprocessing the returns to search for peaks within coarse range segments and then displays/processes these peaks. In the example shown in Figure 15, the 100 Km surveillance extent of the radar is broken into 410 range segments of 250 metres each. Each of these range segments is comprised of 760 resolution cells which would be searched for a peak value which then would be saved, scan to scan integrated and then displayed to the user. There are losses in performance associated with this technique ("collapsing losses") due to the effect that a target now has to compete with the amplitude distribution of the peak of 760 samples of clutter rather than compete with the distribution of the individual clutter samples.

These losses could be offset by coherently processing the complex peak detected samples using the algorithm described above. In order to implement the algorithm, the hardware currently performing the peak detection would have to be modified to measure and save the phase as well as the magnitude when searching for the largest peak within each range segment. For 410 range segments sampled at a PRF of 500 Hz, the data I/O rate would be 205 Kbytes per second. Each of these range segments would then be processed coherently in real time.

The compromise associated with the reduction of data rate is that the measured phase history for a segment containing a target could be "corrupted" by samples in which target was fading and had an amplitude that failed to dominate the segment. In these cases the smooth or deterministic nature of the phase history for a cell containing a target would be degraded by the presence of these "outliers". The quadratic fit algorithm described in the previous section could be modified to make it more robust to this effect by using an ordered statistics approach in which a best fit model for a series of samples from a range segment would be found and the individual samples for this cell then ordered in the size of the deviation from that best fit model. A (small) proportion of those samples showing the greatest deviation would then be disregarded during the calculation of the "goodness of fit" for that particular segment.

5. Conclusions

This report has discussed a method of discriminating between the returns from a patch of the sea surface and from a point target on the surface based on phase. Although this technique has been shown to improve the target to clutter ratio for the experimental data collected so far, there is much work to be done in validation of the algorithm against a wider range of (realistic) environmental and system parameters. In particular it is important to investigate the coherent characteristics of the radar return from the sea surface in high sea states and at longer ranges (ie. from larger patches of

the surface). It is also important to understand more fully the constraints on target amplitude and phase noise required to achieve specific performances.

There are several possible improvements to the algorithms which will lead to a significant reduction in the processing power required. These should also be evaluated more fully, including the use of the first, second and third differences in the phase history as approximations of the instantaneous velocity, acceleration and first derivative of the acceleration of a target. The analysis of these differences directly has been shown to be useful in the discrimination of target returns from clutter.

Another way of making use of the best fit quadratic or cubic function for the phase history would be to use this history to "motion compensate" the returns from each range cell and then add the motion compensated returns coherently. This would be a good way to make use of both amplitude and phase information concurrently (ie. look for bright returns with a target like phase history) and requires further research.

Finally, statistical analysis is required to characterise and predict the improvement in target to clutter ratio resulting from this method for different scan rates and pulse repetition frequencies and for coherently processing peak detected data.

6. Acknowledgments

The author would like to thank the Canadian Department of National Defence and in particular the people of the Defence Research Establishment in Ottawa (DREO), Canada for their support of this research. In particular, thanks are due to George Haslam and Dr Tasos Drosopoulos of this Establishment for the many discussions we have had and the ideas which have arisen from these discussions. This work was carried out by the author whilst on attachment to DREO from the Australian Defence Science and Technology Organisation under The Technical Co-operation Program (TTCP).

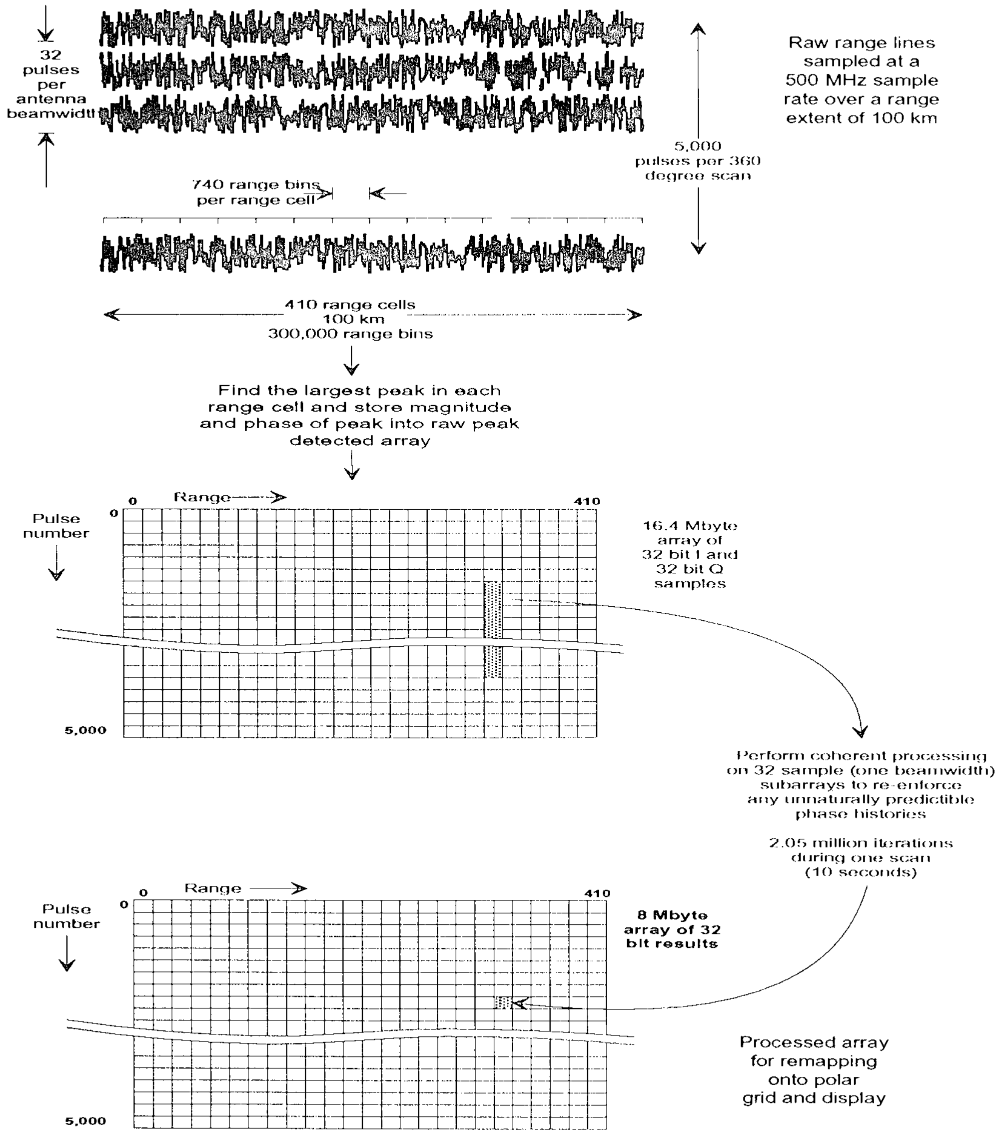

Figure 15 *Block diagram representing the proposed implementation of a target to clutter ratio improvement algorithm, based on coherent processing, in the APS-506 radar.*

7. References

1. Watts, S., *"Radar detection prediction in sea clutter using the compound K-distribution model"*, IEE Proc, Vol. 132, Pt. F, No. 7, Dec. 1985, pp613-620.

2. Chan, H.C., *"Radar sea clutter at low grazing angles"*. IEE Proc, Vol. 137, Pt. F, No. 2, April 1990, pp102-112.

3. Raghavan, R.S., *"A method for estimating parameters of K-distributed clutter"*, IEEE Trans. AES, Vol. 27, No. 2, March 1991, pp238-246.

4. Haslam, G.E., Vant, M.R., DiFilippo, D., *"A synthetic Aperture Radar mode for the AN/APS-506 Radar"*, Proc. IEEE 1988 National Radar Conference, Ann Arbor, Michigan.

5. Smith, J.M., Logan, R.H., *"AN/APS-116 Periscope Detecting Radar"*, IEEE Trans. AES, Vol. 16, 1980, pp66-74.

6. Haykin, S., *"Adaptive Radar Detection and Estimation"*, WILEY, New York, 1992.

7. Longstaff, I.D., Heilbronn, D.J., McDonald, B., *"A low cost Synthetic aperture Radar"*, Proc Radarcon 1990, Adelaide, Australia.

8. Kezys, V, Haykin, S., *"IPIX - A multiparameter X-Band research radar"*, McMaster University, Hamilton, Canada.

9. Papoulis, A., *"Probability, Random Variables and Stochastic Processes"*, McGraw Hill, 1984.

Detection of Small Targets in Sea Clutter Limited Environments Using Phase Information

Brian L. Reid

DSTO-TR-0171

DISTRIBUTION LIST

	Number of Copies
DEPARTMENT OF DEFENCE	
Defence Science and Technology Organisation	
Chief Defence Scientist and members of the)	1 shared copy
DSTO Central Office Executive)	for circulation
Counsellor, Defence Science, London	(Document Control sheet)
Counsellor, Defence Science, Washington	(Document Control sheet)
Scientific Adviser - POLCOM	1
Senior Defence Scientific Adviser	1
Assistant Secretary Scientific Analysis	1
Director, Aeronautical & Maritime Research Laboratory	1
Electronics and Surveillance Research Laboratory	
Director, Electronics and Surveillance Research Laboratory	1
Chief, Microwave Radar Division	1
Research Leader, Microwave Radar	1
Research Leader, Systems	1
Head, Radar Processing	1
Brian Reid	4
Navy Office	
Navy Scientific Adviser (NSA)	1
Army Office	
Scientific Adviser, Army (SA-A)	1
Air Office	
Air Force Scientific Adviser (AFSA)	1
Libraries and Information Services	
Defence Central Library - Technical Reports Centre	1
Manager Document Exchange Centre (MDEC) (for retention)	1
Additional copies which are to be sent through MDEC	
DIS for distribution:	
National Technical Information Centre. United States	2
Defence Research Information Centre, United Kingdom	2
Director Scientific Information Services, Canada	1
Ministry of Defence, New Zealand	1
National Library of Australia	1

Defence Science and Technology Organisation Salisbury, Research Library	2
Library Defence Signals Directorate Canberra	1
AGPS	1
British Library Document Supply Centre	1
Parliamentary Library of South Australia	1
The State Library of South Australia	1
Spares	
Defence Science and Technology Organisation Salisbury, Research Library	6

1. Page Classification
UNCLASSIFIED
2. Privacy Marking/Caveat (of document) N/A

Department of Defence

DOCUMENT CONTROL DATA SHEET

3a. AR Number	3b. Laboratory Number	3c. Type of Report	4. Task Number
AR-009-250	DSTO-TR-0171	DSTO TECHNICAL REPORT	DST 92/438
5. Document Date SEPT 1994	6. Cost Code 842943	7. Security Classification UNCLASSIFIED	8. No of Pages 28

10. Title
Detection of small targets in sea clutter limited environments using phase information.

* U	U	U
Document	Title	Abstract

9. No of Refs 9

S (Secret) C (Confi) R (Rest) U (Unclas

* For UNCLASSIFIED docs with a secondary distribution LIMITATION, use (L) in document box.

11. Author(s)

Brian Reid

12. Downgrading/Delimiting Instructions

N/A

13a. Corporate Author and Address

Electronics & Surveillance Research Laboratory
PO Box 1500, Salisbury SA 5108

14. Officer/Position responsible for

Security: ....N/A...

Downgrading: ....N/A...

Approval for Release: .....CMRD.

13b. Task Sponsor

15. Secondary Release Statement of this Document

APPROVED FOR PUBLIC RELEASE

16a. Deliberate Announcement

NO LIMITATION

16b. Casual Announcement (for citation in other documents)

[✓] No Limitation [ ] Ref. by Author, Doc No. and date only

17. DEFTEST Descriptors

18. DISCAT Subject Codes

19. Abstract

Current techniques used to discriminate between sea clutter and targets, based on using the amplitude of the reflected signal, are described and applied to data collected experimentally. A new method which uses information contained in the phase of the reflected energy is described and is also applied to this data set and a significant improvement in the ability to detect a small target within this data is demonstrated. Issues associated with the implementation of this new algorithm in an existing radar system are then considered and several feasible approaches are described.